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Apparatus for measuring Thermal conductivity of fluids

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Abstract— In recent years Thermal Engineering has developed in many aspects. Due to the development in thermal engineering there is a case for measuring thermal conductivity of the fluids .Thermal conductivity of fluids is measured by Steady state methods as well as Transient method. The Transient Hot Wire has been widely accepted as the most accurate technique over a wide range of fluids. Although the principle of the method is apparent simple, its experimental implementation requires suitable temperature sensing, automatic control, data acquisition, and data analysis systems. Because of the relatively short experimental times and large amounts of parametric data involved in the measurement process, computer control of the measurement is essential. A predetermined current is applied to the hot wire to produce a temperature difference across the fluids. By measuring the temperature differential the thermal conductance of the fluids may be determined.

Index Terms— Thermal conductivity, Transient method, Hot wire method, Nichrome hot wire.

1 Introduction

IN recent days the thermal conductivity of fluids are measured by Transient hot wire method. Many researchers are establishing new ideas, which are focusing on increasing the performance of the apparatus. In this paper, we focus on both the performance and as well as the cost reduction of the apparatus. The selection of material for preparing the apparatus is important to attain higher performance of the apparatus at low cost. Among various methods for measuring the thermal conductivity of fluid, Transient hot wire method is used because of high accuracy in reading. Over the past few years there has been a tremendous increase in cost of the apparatus for measuring the thermal conductivity of fluids. In this study it is believed that the cost of the apparatus will be low than the current apparatus.

Absolute, Steady-state methods of measuring thermal conductivity has become well established and accuracies better than 10 percent has been attained (Ratcliffe, Brit. J. Appl. Phys. 10, 22 (1959); Devyamkovaet a1, Soviet Physics — Solic State, Vol. 2, p. 68) [2].

Although the attainable accuracy of existing techniques, as attested by the general agreement of the fused quartz data, is sufficient for many material characterization requirements, there is something left to be desired. It would be advantageous if the thermal conductivity measurement could be made with the ease and speed of electrical conductivity determinations .Powell has reported, in J. Sci. Instr. 34, 485 (1957) [3], a comparator method which is simple and fast and he obtained 6% measurements on alloys of aluminum, magnesium and iron. His app-roach has possible limitations with regard to surface properties and the hardness of samples. Nevertheless, it suggests that simple techniques can out beat the more time-consuming standard methods.

Many investigations has reported different techniques for the estimation of thermal conductivity of fluids. These investigations have also presented a good deal of controversies. These studies shows that thermal conductivity of fluids depend on a large number of parameters like the shape, size of particle, volume of concentration, surfactants and base fluid etc. The increase in temperature also increase the thermal conductivity of fluids. But the real mechanism behind the increase has not yet been pointed [4]. In present scenario one needs to conduct careful experiments to measure the thermal conductivity with various process parameters. Such experiments will help in establishing the effect of different variables on thermal conductivity. They will also be useful in validation of different models proposed for the enhancement of thermal conductivity of Nano particles.

2 Materials and Methods

2.1 Transient Hot-Wire Method

In this study, a Transient hot-wire method has been adopted because recent advances in Electronic techniques have helped to establish this method as one of the most accurate ways to determine fluid thermal conductivity. The advantage of this method lies in its complete elimination of the effects of unwanted presence in which natural convection gives problems for measurements made with a steady state apparatus. In addition, the method is very fast relative to steady-state techniques.

The major expositions of both theory and application of the Transient hot-wire method were made by Kestin and Wakeham (1978), Roder (1981), and Johns et al. (1988) [5] . A hot-wire system involves a wire suspended symmetrically in a liquid in a vertical cylindrical container. The wire serves both as heating element and as thermometer. Almost without exception, platinum is the most preferred wire.

The mathematical model is to the attempt to calculate approximation of an infinite-line source of heat suspended vertically in an infinite medium. The method is called Transient because the power is applied abruptly and briefly. The working equation is based on a specific solution of Fourier's law and can be found in standard text (Carslaw and Jaeger, 1959) [6]

$$T(t) - T_{\text{ref}} = \frac{q}{4\pi k} \ln\left(\frac{4K}{a^2 C} t\right), \qquad (1)$$

where $T(t)$ is the temperature of the wire in the fluid at time t, T_{ref} is the temperature of the cell, q is the applied electric power, k is the thermal conductivity, K is the thermal diffusivity of the fluid, a is the radius of the wire, and ln $C = g$, where g is Euler's constant.

The relationship given by Eq. (1) implies a straight line for a plot of ΔT versus ln (t). In practice, systematic deviations occur at both short and long times. However, for each experimental measurement, there is a range of times over which Eq. (1) is valid, that is, the relation-ship between ΔT and ln(t) is linear. The slope of the ΔT versus ln(t) relationship is obtained over the valid range, i.e., between times t_1 and t_2, and using the applied power, we calculated thermal conductivity from equation (2)

$$k = \frac{q}{4\pi(T2 - T1)} \ln(t), \qquad (2)$$

where T_2-T_1 is the temperature rise of the wire between times t_1 and t_2. From the temperature coefficient of the wire's resistance, the temperature rise of the wire can be determined by the change in its electrical resistance as the experiment progresses.

Despite the advantages of the Transient hot-wire method, it is impossible to measure the thermal conductivity of electrically conducting fluids because current flows through the liquids, the heat generation of the wire becomes ambiguous, and polarization occurs on the wire's surface. This method is thus normally restricted to electrically non conducting fluids such as noble gases and organic liquids.

Only a few attempts have been made to expand the Transient hot-wire method to measure electrically conducting liquids. Nagasaka and Nagashima (1981) [7] used a platinum wire (diameter Ø40µm) coated with a thin electrical insulation layer (thickness = 7.5µm) to measure the thermal conductivity of an NaCl solution[11], and they analyzed the effects on the thermal conductivity measurement due to this thin insulation layer. Because fluids are likely to be electrically conducting (metallic nanoparticles and the suspending fluid such as water are electrically conducting materials), the ordinary Transient hot-wire technique cannot be used. Therefore,
By replacing the platinum wire from the Nagasaka and Nagashima's[7] method an nichrome wire of diameter Ø0.38mm have been adopted in this experiment.

2.2 Experiment Process

A Transient hot-wire cell was designed and constructed specifically for the measurement of the thermal conductivities of fluids. The experimental apparatus and the electrical circuit used in this study are shown schematically in Fig. 1. In the Wheatstone bridge, Rw is the resistance of the hot wire, R_1 is a 10 kΩ potentiometer, $R2$ is a 1 kΩ resistor, R_3 is a 0.5 Ω resistor. Adjusting the resistance of the potentiometer R, allows the offset voltage from the Wheatstone bridge to be cancelled out and thus the high-voltage gain of the analog-to-digital (A/D) converter can be used[8-10]. Nichrome is used for the hot wire because of its resistance/temperature relationship is well known over a wide temperature range. A Ø0.38mm diameter nichrome wire was used because the other diameter nichrome wires are too fragile .

Switching the power supply from R_1 to the Wheatstone bridge initiates the voltage change in the hot wire, due to the voltage change in the hot wire, heat may occur and this heat will make a change in the temperature rise of the sample fluid . The time taken for the temperature rise has been noted and the values has been compared with the predefined standard values.

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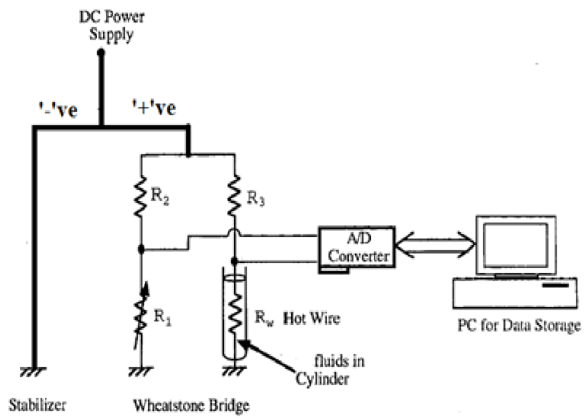


2.3 Circuit Diagram

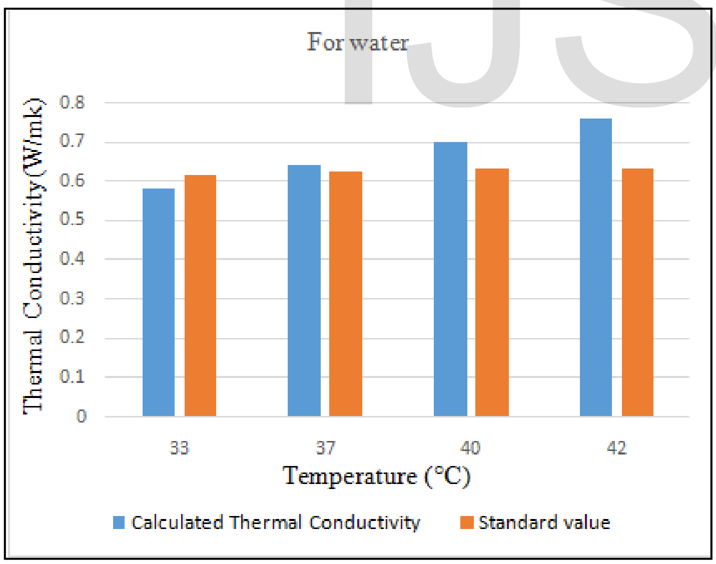
The circuit diagram for apparatus for measuring Thermal conductivity is given below

Figure 1. Measuring the Thermal Conductivity by Transient hot-wire apparatus

3 Result and Discussion

3.1 Thermal conductivity for Water

The figure 2 shows the thermal conductivity of water at calculated thermal conductivity value to the standard thermal con-

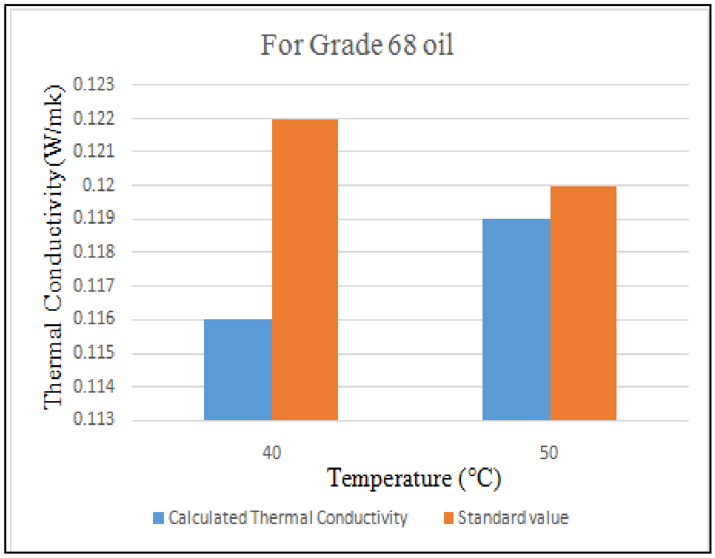


ductivity value at different temperatures. The maximum deviation from the calculated thermal conductivity of water to the standard thermal conductivity of water is about an 12% deviation. The graph for the deviations is given below

Figure 2. Thermal Conductivity vs Temperature for water

3.2 Thermal conductivity for Grade 68 oil

The figure 3 shows the thermal conductivity of water at calcu-



lated thermal conductivity value to the standard thermal conductivity value at different temperatures. The maximum deviation from the calculated thermal conductivity of water to the standard thermal conductivity of water is about an 12% deviation. The graph for the deviations is given below

Figure 3. Thermal Conductivity vs Temperature for Grade 68 Oil

4 Conclusion

To experimentally investigate the thermal conductivity behavior of the fluid we measure the thermal conductivity of two fluids such as water and grade 68 oil by a Transient hot-wire method.

Comparison between the calculated and the standard thermal conductivity was done However the apparatus has a max deviation of 12% which have been accepted by ASTM E1461-07 standard.

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